Public Service Commission of Wisconsin
P.O. Box 7854
Madison, WI 53707-7854

General Information: 608-266-5481
TTY: 608-267-1479
Fax: 608-266-3957
http://www.psc.state.wi.us

6011B   April 1999

PSC Overview Series . . .

Underground Electric Transmission Lines

Public Service Commission of Wisconsin

The Public Service Commission does not discriminate on the basis of disability in the provision of programs, services, or employment. If you are speech, hearing, or visually impaired and need assistance, call (608) 266-5481 or TTY (608) 267-1479. We will try to find another way to get the information to you in a usable form.

This Overview contains information about electric transmission lines which are installed underground, rather than overhead on poles or towers.[1] Electricity consumers, landowners, and state and local government officials who are concerned about a transmission line project in their area may find this information helpful.

[1] Much of the information used in this publication was obtained from the Electric Power Research Institute (EPRI), primarily its Underground Transmission Systems Reference Book, 1992 Edition, and from educational and project materials supplied by Power Delivery Consultants, Inc. of Ballston Lake, New York.

Introduction

An electric transmission line is defined by s. PSC 112.02(8), Wis. Adm. Code, as any line over 40 kV. This kind of electric line moves electricity over long distances and can be compared to county and state highways. Electricity flows along a transmission line’s conductors, which are specially designed bundles of wire. Most transmission lines have three conductors, which are suspended above ground on poles or towers. The conductors are air-cooled. Because overhead transmission line conductors are bare, uninsulated wires, the Wisconsin State Electric Code requires the conductors to be a certain number of feet above the ground, away from buildings and other structures, and away from each other for safety and reliability.

Some transmission lines in Wisconsin have been constructed underground, in pipes, in ducts, or directly buried in the earth. They are generally three to five feet underground, but the distance between the conductors is a matter of inches. Instead of natural air circulation and wide spacing, other methods are used for cooling and for safety and reliability. Underground lines have different technical requirements than overhead lines and they cause different environmental impacts. Due to their different physical, environmental, and construction needs, underground lines generally cost more than overhead lines. This Overview describes types of underground electric transmission lines, the impacts of their siting and operation, how they are built, how reliable they are, and how their cost compares to overhead lines.

For most large underground or overhead transmission lines, the utility must apply to the Public Service Commission (PSC) for approval prior to building the line. Under s. 196.49, Wis. Stats., a utility must obtain a Certificate of Authority (CA) from the PSC before construction can begin on any line that will cost at least 2 percent of the its operating revenues. Under s. 196.491, Wis. Stats., the utility must acquire a special

Certificate of Convenience and Necessity (CPCN) from the PSC before it can begin negotiating right-of-way purchases for lines greater than 100 kV (kilovolts) and more than 1 mile in length.

Issues Discussed in this Overview

The following issues will be addressed in this Overview:

- Types of underground electric transmission lines
- Necessary accessories to all underground lines
- Right-of-way requirements
- Cooling
- Construction
- Costs of underground transmission lines
- Siting impacts: construction, repair, limits to length
- Operating impacts: magnetic fields, heat, leaks, safety needs
- Reliability of service: repairs, outages, life expectancies, overhead vs. underground lines

Types of Underground Electric Transmission Lines

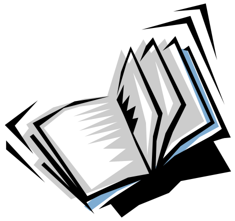
There are several types of underground transmission lines, classified by: 1) whether or not they require pipes and 2) what they use for insulation. The main types are:

- High-pressure, fluid-filled pipe (HPFF)
- High-pressure, gas-filled pipe (HPGF)
- Self-contained fluid-filled (SCFF)
- Extruded dielectric (XLPE, for "cross-linked" polyethylene, the plastic insulation)

Fluid-filled (HPFF) types are the most common in the United

- Merchant Plants and Other Non-Utility Generation
- Nuclear Power Plant Decommissioning and Radioactive Waste Disposal
- Renewable Energy Resources
- Right-of-Way and Easements in Electric Facility Construction

To obtain any of these Overviews, contact the Public Service Commission, by phone (608) 261-8524 or e-mail *pscrecs@psc. state.wi.us*, or check our home page at: http://www.psc.state.wi.us.



David Valine
Wisconsin Public Service Corporation
P.O. Box 19002
Green Bay, WI 54307-9002
(920) 433-1294

Pamela Rasmussen
Northern States Power Company
P.O. Box 8
Eau Claire, WI 54702-0008
(715) 839-4661

Craig Fenrick
Madison Gas and Electric Company
P.O. Box 1231
Madison, WI 53701-1231
(608) 252-7959

Electric Power Research Institute (EPRI):

Ralph W. Samm
Electric Power Research Institute
3412 Hillview Avenue
Palo Alto, CA 94304

PSC Overview Series

The Public Service Commission has prepared other Overviews for important electric issues. These are:

- Air Quality Issues for Electric Power Generation
- Common Power Plant Siting Criteria
- Electric Energy Efficiency
- Electric Power Plants
- Electric Transmission Lines
- EMF -Electric and Magnetic Fields
- Environmental Impacts of Electric Transmission Lines

States. Self-contained (SCFF) types are the least common and least likely to be used in Wisconsin due to climate. This Overview focuses on the two pipe-type lines (fluid-filled and gas-filled) and the extruded dielectric type (XLPE).

High-pressure, fluid-filled pipe type (HPFF)

A high-pressure, fluid-filled pipe type of underground transmission line, consists of a steel pipe which contains three high-voltage conductors. Each conductor is made of copper or aluminum, insulated with high-quality, oil-impregnated kraft paper insulation, and covered with metal shielding (usually lead), and skid wires (for protection during construction). The conductor and its wrappings are often referred to as “cables.” The cables are surrounded by a dielectric fluid. This fluid is an insulator and does not conduct electricity. Figure 1 shows a gas-filled pipe type line. The fluid-filled type would look similar in cross-section.

The steel pipe protects the conductors from mechanical damage and water infiltration and prevents fluid leaks. The pipe itself is protected from the chemical and electrical environment of the soil by means of a coating and cathodic protection.

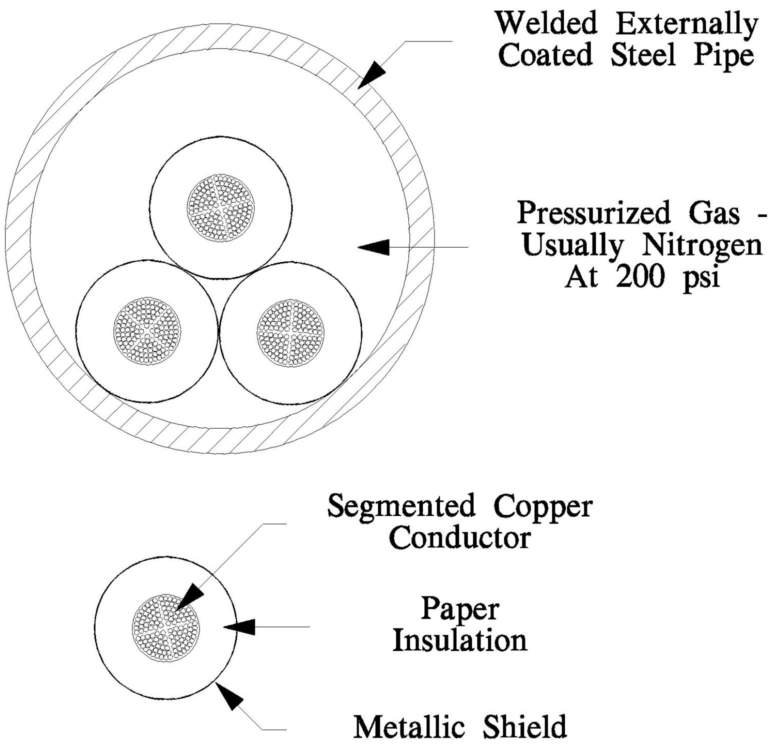
The dielectric fluid is an oil, at 200 pounds per square inch, which saturates the kraft paper insulation. This pressurized fluid prevents electrical discharges in the conductors’ insulation. (Electrical discharges cause the line to fail.) The fluid also moves heat away from the conductors. The fluid is static and removes heat by conduction.

High-pressure, gas-filled pipe type (HPGF)

The high-pressure, gas-filled pipe type of underground transmission line is a variation of the HPFF pipe type, described above. Instead of dielectric oil, it uses pressurized nitrogen gas. The nitrogen gas is less effective than dielectric fluids at suppressing electrical discharges and cooling. To compensate for this, the conductors' insulation is about 20 percent thicker than the insulation in fluid-filled pipes. Thicker insulation and a warmer pipe reduce the amount of current the line can safely and efficiently carry. However, this type of line operates well in Wisconsin's low winter temperatures. Figure 1 illustrates this type of line.

Self-contained, fluid-filled pipe type (SCFF)

Figure 1 High Pressure Gas Filled Pipe Basic Design



individual may contribute to the extra cost (beyond the cost of a comparable overhead line). If that municipality, company, organization, or individual is willing to bear the extra cost, the underground line is more likely to win PSC approval.

Whom can I Contact for Further Information

Kenneth Rineer
Public Service Commission of Wisconsin
P.O. Box 7854
Madison, WI 53707-7854
608-267-1201
rineek@psc.state.wi.us

Utility contacts:

Michael Smalley
Wisconsin Electric Power Company
P.O. Box 2046
Milwaukee, WI 53201-2046
(414) 221-3163

For Wisconsin Power and Light Company:

Kathryn Trudell
Resource Strategies, Inc.
634 West Main Street, Suite 202
Madison, WI 53703
(608) 251-1125

Choosing between underground and overhead construction

The choice to build an underground transmission line instead of an overhead line depends on a number of factors.

Except for special structures to connect it to the existing overhead system, an underground line would be relatively out of sight. It would also create much lower magnetic fields. These values might make it an attractive option in a residential or suburban area, especially where there is little concern about whether bushes or trees can be grown in the ROW.

While there is concern about the potential for an oil leak from a HPFF pipe-type line, the HPGF and XLPE types do not involve these oils. They may be more limited in the current they can carry. They would still require the special termination structures to connect them with the above-ground system.

The need for a trench increases the possibility of environmental disruptions from underground lines. The soil must be treated with care to preserve its ability to drain and to support the natural vegetation or crops. In a wetland, it is difficult to avoid disrupting the vegetation, soil microbiology, and water flow.

The trench and concrete vaults make an underground line more expensive. The line's relative costs would become greater if the trench needed to be installed in winter or through a contaminated area requiring special disposal techniques for the soil that is removed.

All factors must be balanced with the underground line's relatively higher cost. At present, new transmission construction is one of the costs that a utility can pass through to its customers. If passing the added cost to ratepayers of putting a transmission line underground is not in the public interest, the interested local municipality, company, organization, or

The self-contained, fluid-filled pipe type of underground transmission line is often the choice for underwater transmission lines. The conductors are hollow and filled with an insulating fluid that is pressurized to 25 to 50 pounds per square inch. In addition, the three cables are independent of each other. They are not placed together in a pipe.

Each cable includes the fluid-filled conductor, insulated with high-quality kraft paper and protected by a lead-bronze (or aluminum) sheath, and a plastic jacket. The fluid reduces the chances of electrical discharges and line failure. The lead-bronze (or aluminum) sheath helps pressurize the conductor's fluid and the plastic jacket keeps water out.

Extruded dielectric, polyethylene (XLPE)

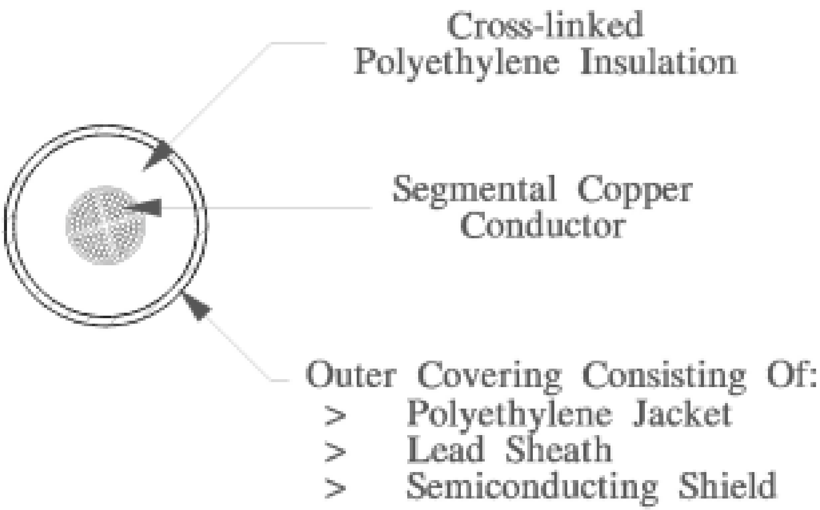
The extruded dielectric polyethylene pipe type of underground transmission line, often called "solid dielectric," is becoming the standard nationally for underground 69 kV and 138 kV electric lines. This type of line relies on close manufacturing control to eliminate any contaminants or voids in the insulation that could lead to electrical discharges and breakdown of the line from electrical stress. The solid dielectric material replaces the pressurized liquid or gas of the other line types.

This type of construction has three independent cables. They are not housed together in a pipe, but are set in concrete ducts or buried side-by-side directly in specially prepared soil. Each cable consists of a copper or aluminum conductor, a semi-conducting shield, the special insulation (usually cross-linked polyethylene, or XLPE), another semi-conducting shield, a metallic shield or sheath (usually lead), and a plastic jacket. The insulation is about twice as thick as the oiled insulation used in other line types. Figure 2 shows the XLPE in cross-section.

Accessories

The following structures are called "accessories," because they

Figure 2 Cross-Linked Polyethylene Basic Design



are part of all types of underground electric transmission lines. They are also responsible for 90 percent of all underground line failures.

Splices

Splices join pieces of conductor. Splices are needed because there is a limit to the amount of cable that can be put onto a spool for shipping and there is a limit to the amount of tension a cable can withstand as it is pulled into a pipe. The length that works best also depends on the number of bends and dips in the line. XLPE type lines need a splice every 900 to 2000 feet. Pipe type lines need a splice at least every 3,500 feet.

Pipe type lines require a concrete work vault to hold each splice. While the connecting piece is only about 7.5 inches long, the materials needed to reduce the electrical stress results in a joint about 63 inches long (over 5 feet). This means that

To locate a leak in a pipe-type line, the pipe pressure must be reduced below 60 pounds per square inch and the line de-energized before any probes are put into the pipe. For some leak probes, the line must be out of service for a day before the tests can begin. Pipe pressure must be returned to normal slowly. This would require an additional day or more before the repaired line could be energized.

To locate an electrical fault for an underground line, the affected cable must be identified. To repair a pipe-type line, the fluid on each side of the electrical failure would be frozen at least 25 feet out from the failure point. Then, the pipe would be opened and the line inspected. A splice would be made (or replaced) and some cable may be replaced and spliced. Then, the pipe would be thawed and the line would be repressurized, tested, and put in service.

In contrast, a fault or break in an overhead line can usually be located almost immediately and repaired within hours or, at most, a day or two.

One problem that increases emergency response time for underground transmission lines is that most of the suppliers of underground transmission materials are in Europe. While some of the European companies keep American-based offices, cable and system supplies may not be immediately available for emergency repairs.

Line life expectancies

While the assumed life of underground pipe type or XLPE cable is about 40 years, there is pipe-type cable that has been in service for more than 60 years. Overhead lines in northern Wisconsin have an assumed life for accounting purposes of about 32 years, but the lines actually last about twice as long.

Consultants, Inc., using some French data and the results of an informal survey, generated estimates that correspond to about:

- One cable repair needed per year for every 1,000 miles of cable.
- One splice repair needed per year for every 1,428 miles of cable.
- One termination repair needed per year for every 1,428 miles of cable.

These trouble rates indicate that there would be at the most a 1:1,000 chance for the most common type of repair to be needed in any one mile of XLPE underground line over any one year.

Outage times

The duration of outages varies widely, depending on the circumstances of the failure, the availability of parts, and the skill level of the repair personnel. Failure of an HPGF termination can be repaired in two days, but the duration of typical HPGF outages is 8 to 12 days. The duration of typical XLPE outages is 5 to 9 days. Wisconsin Electric Power Company operates a large amount of HPFF line and estimates from 2 to 9 months to repair a fault on a HPFF system, depending on the extent of the damage.

The outage rate would increase as the number of splices increases, but use of concrete vaults at splice locations can reduce the duration of a splice failure by allowing quick and clean access to the failure. The outage would be longer if the splice were directly buried, as is sometimes done with rural or suburban XLPE lines. If the splice location is in an awkward place, such as a road intersection or a family backyard, the inconvenience of repair that is avoided with a concrete vault could make up for the inconvenience that occurred during its construction.

the vault must be at least 135 inches long (over 11 feet). Typically, the hole dug for a vault is over 15 to 20 feet long and about twice as wide as the trench for the pipe. There are typically one or two “chimneys” or vents to the surface closed with steel covers. The strength of the concrete must withstand the load of overhead traffic. Vaults are generally not located under sidewalks or within 125 feet of street intersections. About two-thirds of XLPE splices are typically in permanent concrete vaults and one third are typically in temporary vaults, which are not lined with concrete and are filled in after construction. If the XLPE is installed in concrete ducts, all splices would be in permanent, concrete vaults.

Terminations

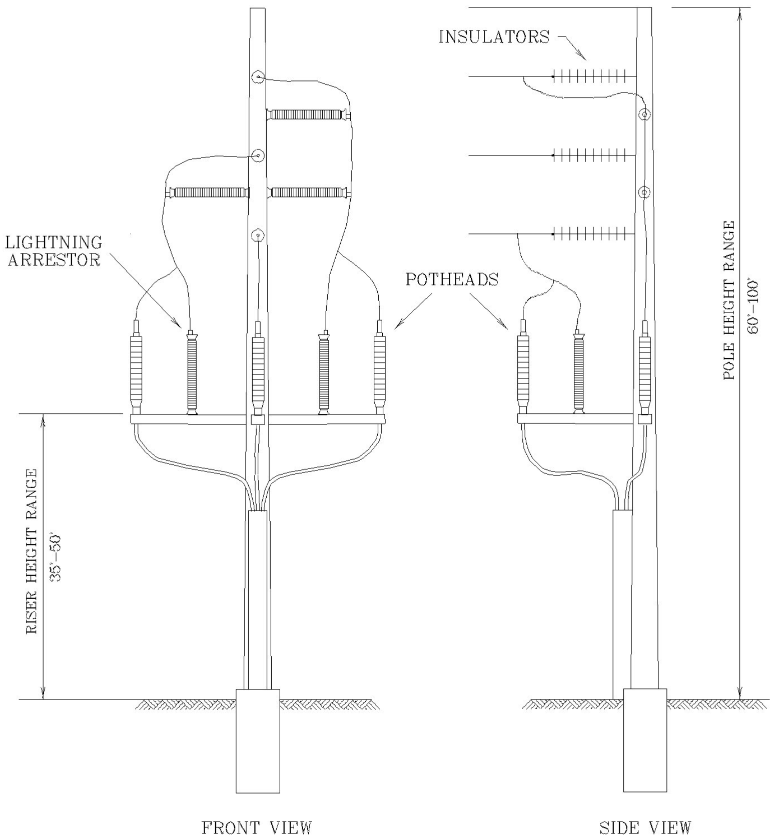
Underground lines terminate (connect to overhead lines or to substations) by means of “risers,” which are fastened to above ground structures. Three spread arms (the “spreaderhead”) carry the underground line above ground and separate the three conductors so that they meet electric code requirements for the spacing of lighter, overhead conductors. If spreaderheads are placed underground, they are called “trifurcators” and may be placed in a concrete vault. Porcelain insulators or “housings,” contain the actual connections between the in-earth and in-air portions of the line. (These housings are often called “potheads.”)

Terminations also keep moisture out of the underground system and provide electrical grading between the underground and overhead portions of a line. Terminations are often located in substations. An example of a termination with a spreaderhead is shown in Figure 3.

Pressurizing sources

For an HPFF system, a pressurizing plant maintains fluid pressure in the pipe. The pressurizing plant is located on one end of the line, usually within a substation fence. It includes a

Figure 3 Diagram of a Typical Riser Structure



reservoir that holds reserve fluid. An HPGF system does not use a pressurizing plant, but rather a regulator and nitrogen cylinder. These are located in a "gas-cabinet" that contains high-pressure and low-pressure alarms and a regulator. Sometimes, a longer SCFF line that varies in elevation has equipment about every mile at splice points to maintain equal pressure throughout its length. The XLPE system does not require any pressurization.

Right-of-way Requirements

against accidental future dig-ins, a concrete duct bank, a concrete slab, or patio blocks are installed above the line, along with a system of warning signs ("high-voltage buried cable"). The ducts themselves are electrically inert, but not as mechanically strong as concrete, tile, or soapstone ducts of years past. They are now generally polyethylene, polyvinylchloride (PVC), or fiberglass.

Reliability of Service

In general, underground transmission lines are very reliable. However, their repair times are much longer than those for overhead lines.

Repair rates -pipe type lines

For pipe-type lines, the most recently calculated trouble rates (in 1987, for about 2,536 miles of line, by Power Delivery Consultants, Inc.) correspond to about:

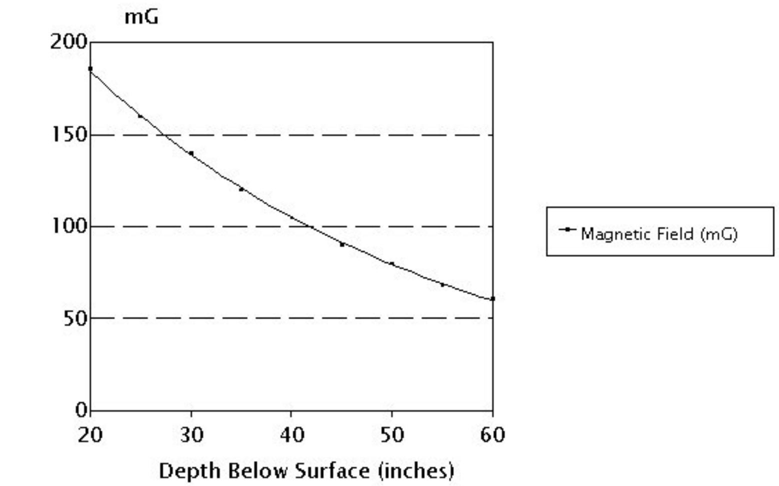
- One cable repair needed per year for every 833 miles of cable.
- One splice repair needed per year for every 2,439 miles of cable.
- One termination repair needed per year for every 359 miles of cable.

These trouble rates indicate that there would be at the most a 1:300 chance for the most common type of repair to be needed in any one mile of pipe-type underground line over any one year.

Repair rates -XLPE lines

XLPE trouble rates are harder to find. Power Delivery

Figure 12 Magnetic Field Changes With Depth Below Surface



From Power Delivery Consultants, Inc., EPRI workshop, May 1996.
Measured 3 feet above the centerline for underground transmission.

A nitrogen leak from a HPGF line would not affect the environment, but workers would need to check oxygen levels in the vaults before entering. Fluid leaks are not a problem for solid dielectric cables.

Safety measures

During construction, barricades and warning signs during the day and illuminated flashing signs and lamps at night would guide traffic and pedestrians. After each day's work, steel plates should cover any open trench. All open concrete vaults would have a highly visible fence around them. When the cable is pulled into the pipe the contractor should have the work area cordoned off.

To protect concrete duct (for SCFF and XLPE lines, Figure 9)

Construction or repair under city streets requires a minimum 20-foot wide right-of-way (ROW). See Figures 4 and 5. Support work may require occasional use of an additional lane of the street. Concrete vaults also require more than the minimum. In open country, a wider 30 to 50 foot ROW is used (Figure 6). However, short stretches of 20-foot wide ROW are possible in rural areas where the passage for the line is narrow over a short distance (Figure 7).

The ROW is maintained free of trees or large shrubs, which could interfere with the underground line directly (with their roots) or indirectly (by removing soil moisture which is needed to adequately cool the conductors). Buildings are also prohibited in the ROW, since they would interfere with maintenance and repair work.

Figure 4Typical Work Progression for Underground Pipe Type Installation in a City Street

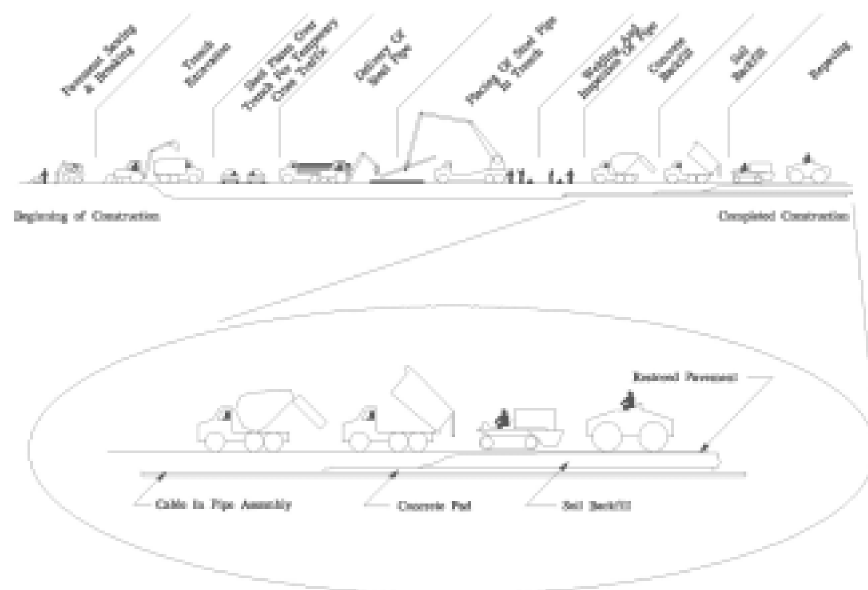
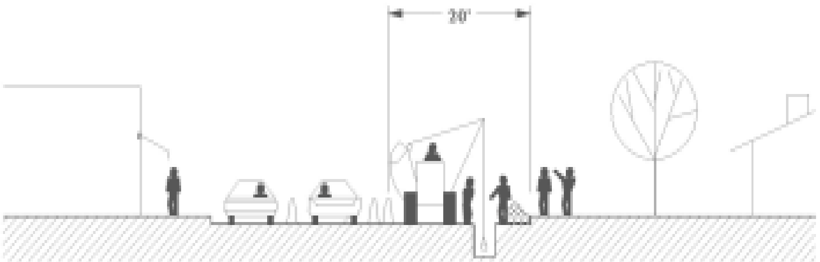


Figure 5 Minimum ROW for Underground Construction in Urban and Suburban Areas



Cooling

Electrical conductors produce heat. Pipe type conductors operate at about 167° to 185° F (with an emergency operating temperature of 212° to 221° F). XLPE conductors operate at about 176° to 194° F (with an emergency operating temperature of about 266° F). Heat must be carried away for the conductors

Figure 6 Typical ROW Needs for Underground Construction in Unpaved Areas

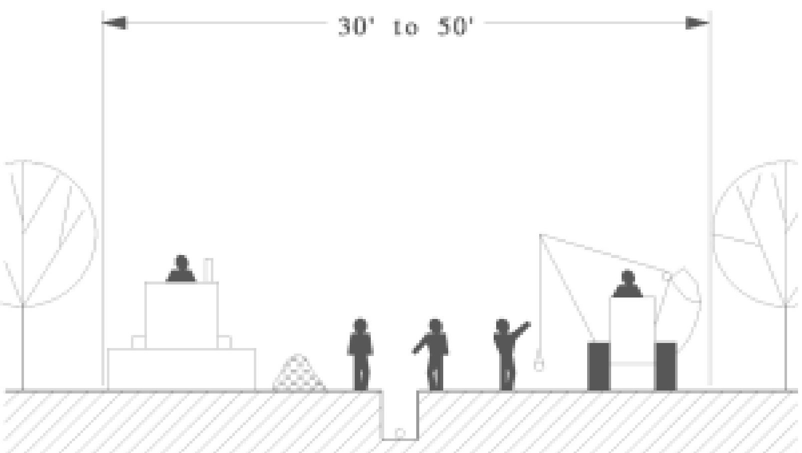
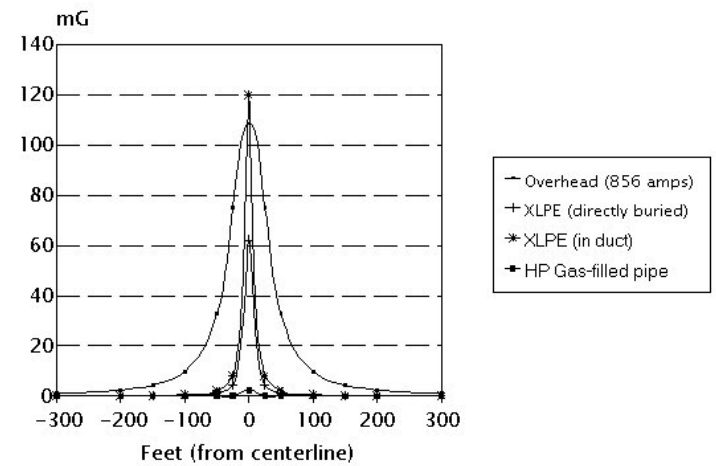


Figure 11 Magnetic Field Strength Within 300 Feet of 138 kV Electric Lines



Data obtained from 1996 WPS application, PSC Docket 6690-CE-176.
Comparing overhead at 856 amps with 3 underground options at 1070 amps.

Potential fluid leaks

Although underground transmission lines require little maintenance, transmission owners must establish and follow an appropriate maintenance program. Otherwise pipe corrosion can lead to fluid leaks.

Both HPFF and SCFF lines must have a spill control plan. The estimate for potential line leakage is about one leak every 25 years. Any dielectric oil leak would be classified as a hazardous waste. This means that any contaminated soil or water would have to be removed for disposal. The types of dielectric fluid include alkylbenzene (which is used in making detergents) and polybutene (which is chemically related to styrofoam). These are not toxic, but are slow to degrade. The release and degradation of alkylbenzene could cause benzene compounds to show up in plants or wildlife (benzene is a known carcinogen).

To learn more about EMF, please refer to the Overview entitled EMF - Electric and Magnetic Fields.

Table 3 Practical Lengths of Underground High-Voltage Cables

[1] The longest XLPE circuit is only about 11 miles long.

Voltage	Cable Type	Practical Length
138 kV	HPFF, HPGF	23 miles
138 kV	XLPE	66 miles[1]
345 kV	HPFF	14 miles

Pipe type underground lines can have significantly lower magnetic fields than overhead lines or other kinds of underground lines, because the steel pipe has magnetic properties that can reduce the field produced by the cables inside it. Maximum magnetic field strengths one meter above the cables of a pipe type line rarely exceed 5 mG.

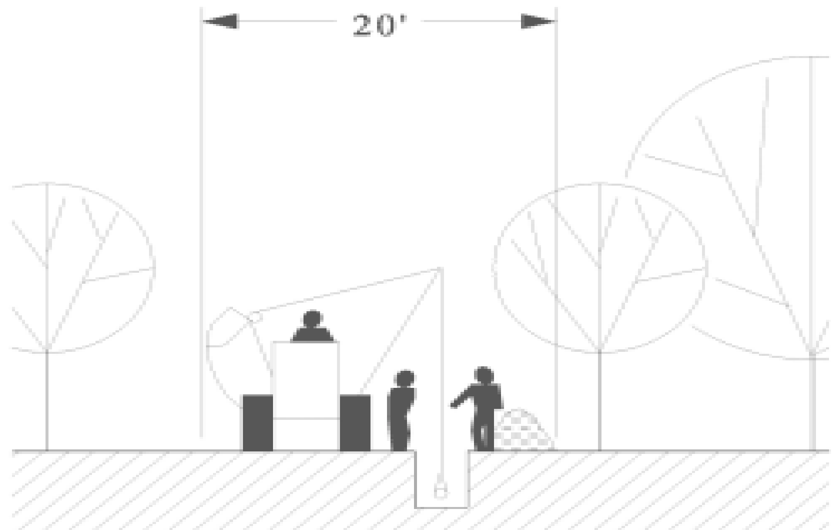
The soil itself has no effect on the magnetic fields. Fields decrease with soil depth because greater depth equals greater distance from the underground line.   See Figure 12.

Heat

Heat produced by the operation of an underground line raises the temperature a few degrees at the surface of the earth above the line. This is not enough heat to harm growing plants, but it could cause premature seed germination in the spring. Heat could also build up in enclosed buildings near the line.

Transmission routes that include other heat sources, such as steam mains, should be avoided. Electric cables should be kept at least 12 feet from other heat sources. Otherwise the cable's ability to carry current decreases.

Figure 7   Minimum ROW for Short Distances of Underground Construction in Unpaved Areas



to continue to carry electric current efficiently. The air performs this function for overhead lines. The soils in and around the trench do this for underground lines.

Insulation removes about 10 percent of cable heat, and ductwork removes about 15 percent. The soil must remove about 75 percent. Soil varies in its ability to transfer heat. Saturated soils conduct heat more easily than soils with air pockets or dry places. For this reason, the soil nearest the line must not be allowed to dry out. (Soil has a tendency to dry out at temperatures of 40° to 122° F. Wisconsin's soil temperatures are around 72° F in the summer and 64° F in the winter at the depth where lines are buried. They are perpetually drying when moisture from precipitation or groundwater flow is not soaking into them.) For many lines, good heat transfer to surrounding soil or groundwater depends on the quality of a specially prepared backfill material replacing the soil in the trench around the line. The backfill material is designed to move heat away from the line.

Construction

Methods

Most construction for an underground transmission line involves: 1) trenching; 2) laying and welding pipes or pouring concrete conduits; 3) replacing soil and closing the trench; 4) pulling cable between vaults; 5) splicing cables; and 6) adding fluids or gas. Testing and evaluation are done throughout the process. If water is encountered, special pumping techniques are used. Figure 4 shows the flow of the construction process. Table 1 shows how long, on average, trenches are open. Table 2 shows typical clearances from other underground facilities that are accepted as good engineering practice.

The absolute minimum clearances for electric transmission lines are described in the Wisconsin Electric Code (ch. PSC 114, Wis. Adm. Code), but pipe-type cable systems are not specifically addressed. The practical clearance requirements in Table 2 are based on accepted good engineering practice. Underwater lines have special construction needs and impacts, which are not addressed in this Overview.

A line would normally be buried about 3.5 to 4.0 feet beneath the surface. However, if the frost line is at or below that depth, burial might be deeper. Trenches for pipe type, XLPE in duct and XLPE directly buried, are illustrated in cross-section in Figures 8, 9, and 10.

Most underground line construction uses a self-propelled,

farming practices and the weather. Backfill (usually about 10 inches) in farmland must be kept deep enough to allow farm work above it. In natural areas, herbaceous vegetation should be allowed to return to the ROW.

Directional boring can be used to avoid many surface features, such as rivers, roads, or landfills. However, expertise is needed to avoid covering the landscape with mud or grout pushed up through weak seams in the rock.

Practical limits to the length of underground transmission lines

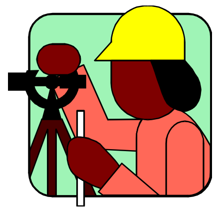
The ‘Practical Length’ for an underground electric transmission line is the length of line that would avoid expensive intermediate facilities along its route to boost the conductor cables’ current-carrying ability. However, actual lengths are generally shorter because there are other electrical factors that limit length. Table 3 illustrates Practical Lengths for some of the higher transmission line voltages found in Wisconsin.

Operating Impacts

Magnetic fields

Generally, underground transmission lines reduce magnetic fields (EMF). Underground lines bring the conductors closer together than is possible with an overhead line. While the magnetic field directly over an underground transmission line can be very high, the closeness of the conductors increases the cancellation effect. This means that the magnetic fields from an underground lines will diminish much more rapidly with distance from the line. See Figure 11 for example. Milligauss (mG) is the common measurement of magnetic field strength.

overhead lines disturb the soil primarily at the locations of the transmission poles or structures. The underground line's ROW must be kept clear of trees and bushes, while small trees and bushes are allowed on an overhead line's ROW. However, in suburban and urban areas, the primary impacts of overhead lines (aesthetics, concerns about electric and magnetic fields [EMF], and concerns about property values) are minimized by underground lines, which cannot be seen, require a far narrower ROW, and can generate lower EMF fields than overhead lines.



Construction and repair impacts in suburban and urban areas

The construction impacts of underground lines are temporary and, for the most part, reversible. They include dirt, dust, noise, and traffic disruption. Increased particles in the air can cause health problems for people who live or work nearby. Particularly sensitive persons include the very young, the very old, and those with health problems, such as asthma. If the ROW is in residential areas, construction hours and the amount of equipment running simultaneously may need to be limited to reduce noise levels. In commercial or industrial areas, special measures may be needed to keep access to businesses or to control traffic during rush hours.

Construction and repair impacts in farmland and natural areas

Soil compaction, erosion, and mixing are serious problems in these areas, in addition to dust and noise. During construction, special methods are needed to avoid mixing the topsoil and lower soil horizons and to minimize erosion. The special soils often placed around the underground line to enhance cooling may slightly change the responsiveness of surface soils to

Table 1 Open Trench Characteristics

Line Type	Size of Open Trench	Time Open (average)	Notes
Pipe-type	about 600 feet	5 work days	Cables are pulled from vault to vault after the pipes are installed.
HPGF	about 600 feet	2 to 3 work days	Uses 40 foot pipe lengths and fluidized backfill.
XLPE, in concrete ducts	about 600 feet	6 to 7 work days	Requires laying and curing concrete ducts.
XLPE, direct buried	1,000 to 2,000 feet	10 work days	Limited to urban or suburban areas. Temporary vaults are backfilled.

Table 2 Clearance Requirements for Trenching

Facility	Clearance in Feet if Parallel	Clearance in Feet if Crossing
Storm sewer	1	1
Water	1.5	1.5
Natural gas	1	1
Electric distribution duct bank	10	2
Telephone distribution duct bank	1	1
Steam	10	4

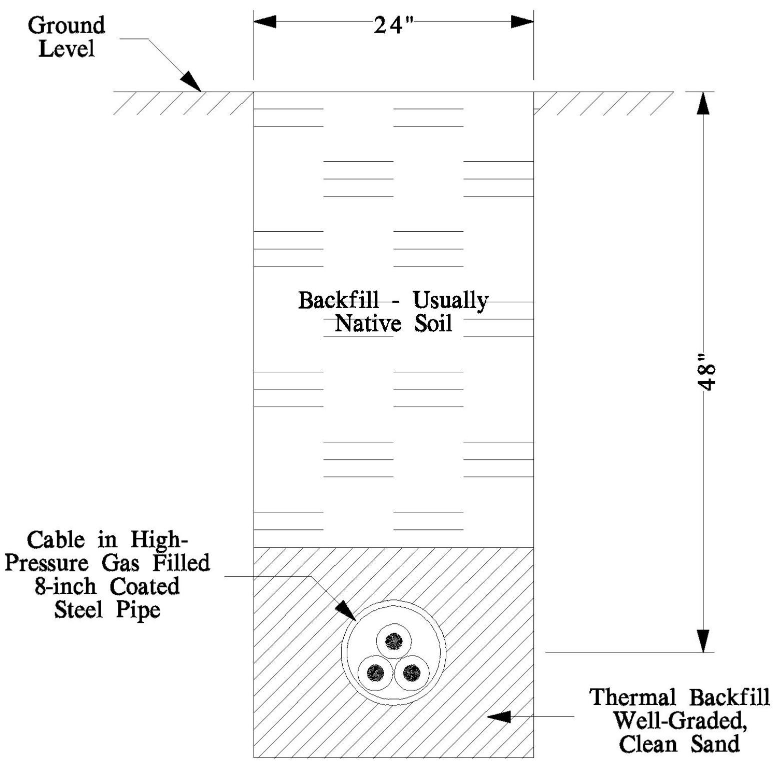
pneumatic-tired crane. Some companies use side-boom crawlers, which are slower and not as versatile in city streets. The welding of pipe sections takes place either in or over the trench. A municipality may or may not allow on-site storage of construction materials or excavated soil along city streets. Sometimes, a transport trailer is left at the site to provide a storage place and work platform.

Pipe welds are x-rayed, then protected from corrosion with plastic coatings. When the pipe is completely installed, it is pressure tested with either air or nitrogen gas. It is then vacuum tested, vault to vault, which also dries the pipe.

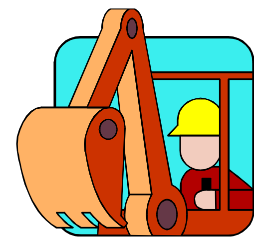
Costs

Underground transmission usually cannot compete with overhead transmission in dollar cost. Costs of underground construction can range from two to ten times as much as an equivalent length of overhead line. However, simple cost ratios of underground to overhead options should not be used because costs are site-specific.

Figure 8 Placement of HPGF System



Repair costs for an underground line would usually be greater than those for an equivalent overhead line. If line construction were to occur on private property, the easement might require the owner of the property to be compensated for a 3-day to 2-week disruption in property use and some property damage. However, the cost to compensate the landowner would probably be small compared to the total repair cost. Leaks can cost $50,000 to $100,000 to locate and repair. A leak detection system for a HPFF cable system can cost from $1,000 to $400,000 to purchase and install depending on the level of sophistication.



Molded joints for spices in XLPE line would cost about $20,000 to repair. Field-made splices would cost up to $60,000 to repair.

A fault in a bored section of the line would require replacement of the entire bored section of the line. If the line were HPGF, for example, it would cost $25 per foot in 1997 for each of three cables for the entire length of the bore. The cables in the bore twist around each other in the pipe so they all would have to be brought out for examination.

Siting Impacts

The impacts of underground transmission lines differ from those of overhead transmission lines. Generally, underground lines would have fewer impacts than overhead lines in urban and suburban areas, while overhead lines would have fewer impacts in farmland or natural areas, such as forest and wetlands. This difference is mostly due to the impacts of soil disturbance and ROW maintenance. Both of these are greater for underground lines than for overhead lines and, therefore, cause greater impacts in farmland or natural areas. Impacts arising from soil disturbance are greater because underground lines require trenching for the entire length of the line, while service facilities, and major streets or highways.

There might need to be protective barriers installed. Extra protections would add to the project cost.

There are a few potential impacts of an underground line that would actually make a line impossible to build. The costs of such a line, however, are generally high enough that obstacles that would increase costs more could make the underground option an uneconomic one. A 20 foot storm sewer would just increase excavation costs. Bedrock could increase the construction cost from $50 per yard in soil to $200 per yard in the rock for too long a distance. Civic groups that organize and successfully oppose construction could increase costs of obtaining approvals, permits, or easements. Hazardous waste sites on the route might cost too much to remediate.

A soil thermal survey may be necessary before construction to help determine the soil's ability to move heat away from the line. If the thermal survey and special backfill have a big effect on costs, they could affect whether an underground option is chose.

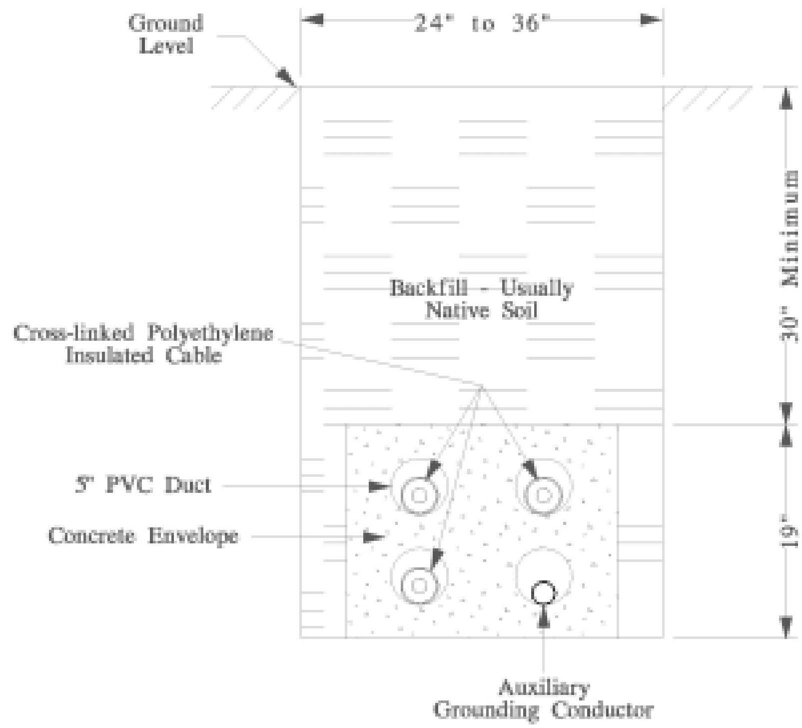
Who would pay for construction?

Who would pay for the more expensive underground option if it were selected by the Commission? The costs could be included in the rate base that the utility could claim through its rates to customers. Then, all the utility's customers would pay a portion of the cost.

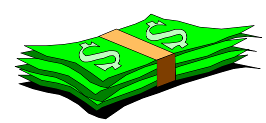
Who would pay the costs of the more expensive underground option if it is not the one selected by the Commission? The costs would have to be covered by a third party, perhaps the landowners agreeing to pay the utility for the different kind of line.

Repair costs

Figure 9 Placement of XLPE in Ducts

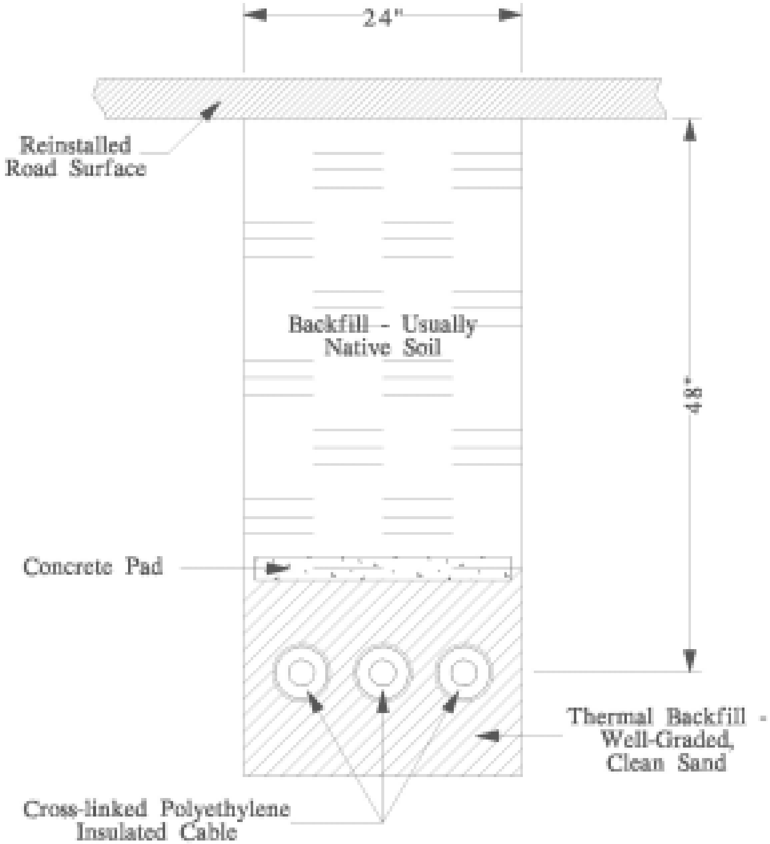


Site and route considerations



Underground construction could be a reasonable alternative to overhead in an urban area where an overhead line cannot be installed with appropriate ROW at any price. In suburban areas, aesthetic issues, weather-related outages, some environmental concerns, and the high cost of some rights-of-way could make an underground option more attractive. An underground line might allow a shorter route to

Figure 10 Placement of XLPE Directly Buried



be used. Or, an underground line along a road corridor could reduce the land needed for easements to an insignificant amount.

The shortest route might not always be the lower cost route. Fewer obstructions or less traffic may make a longer route more appropriate. Timing problems may increase costs. For instance, restrictions on construction in the street or across a street might be appropriate during the morning or evening rush hours. There might be a noise limitations that prohibits

construction noise in the late evenings and night times. The time it takes to install a line would be increased by these restrictions.

Dollars

For an underground line, construction would account for more than 60 percent of the total project cost. In 1997, the cable itself would cost about $20 to $22 per foot depending on the type of line. Dielectric oil would be about $10 per pipe foot and nitrogen would be about $0.50 per foot. Construction in a city street would be about $2.1 million per mile. Corresponding costs of overhead construction would be $500,000 per mile, the exact cost depending on route details.

Costs of gas-or fluid-filled potheads would be around $15,000 each and six are needed for one circuit of three cables in a line. The larger pole and spreaderhead for overhead terminations would cost more than a simple overhead transmission pole. An underground trifurcator would include the cost of excavation.

Costs of the concrete work vaults would be about $35,000 per vault. If there were a vault at the location of every splice, there would be a vault every 900 feet or so with XLPE lines and every 3,500 feet or so with pipe-type lines.

Pressurizing sources would typically cost about $250,000 to $300,000 per plant. There could be one larger plant at one end of the line or a smaller plant at each end. The fluid is flammable, so two plants would offer more reliability while doubling the pressurization costs.

Obstacles and costs

Costs could also increase with the number of obstacles that need to be crossed, such as streams, railroads, other utilities and